

NUMERICAL ANALYSIS OF FLYCASTING MECHANICS

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INTRODUCTION

Fly fishing differs significantly from other forms of sports fishing largely due to the equipment that the angler employs. In fly fishing, an angler casts a lightweight artificial fly by using the distributed weight of the fly line. The motion of the fly line is controlled in part by the motion of the fly rod (i.e., by the angler) as well as by other forces including air drag, gravity and line tension. The casting action is achieved by establishing a nonlinear wave, simply referred to as a *loop*, that propagates along the line. Ultimately, this loop reaches the end of the fly line where it unrolls on or near the surface of the water. By contrast, in spin or bait fishing, an angler casts a lure/bait/weight that has significant weight compared to the line to which it is attached. In this instance, the lightweight line remains largely straight and is simply pulled from a reel under tension.

Most anglers require considerable practice to develop proficiency in flycasting. The sheer amount of practice required to develop highly skilled casting techniques underscores the subtle mechanics involved in casting a fly line. Only a limited number of technical papers have addressed the underlying physics of the fly line during casting and these are also contained in a bibliography available on a website by Spolek [1]. Of these, three publications [2-4] are most directly related to this study as they introduce various models of the fly line.

In [2], Spolek introduces an idealized model of the fly line for an overhead cast by *prescribing* the geometry of the line. Thus, the line kinematics are determined *a priori* by dividing the line into three segments. A straight horizontal segment starts at the tip of the rod and is attached to a semi-circular loop segment that is then attached to a final straight horizontal segment. A work-energy balance is used to study the propagation of the ideal semi-circular loop. Results from this energy balance reveal the key effects caused by tapering the fly line and by air drag on the loop segment. A refined drag model was subsequently offered in [3]. In [4], Robson relaxes the kinematic constraints in [2] and introduces a multi-body approximation of the fly line. The fly line is modeled as a sequence of particles connected by

small massless and rigid rods. The rods are then pinned connected and relative joint angles are introduced leading to a large degree-of-freedom lumped parameter model. The motion of the tip of the fly rod is prescribed as the input to this model that is then used to simulate the response of the fly line under the action of gravity and drag. The geometry of the line predicted by simulation is in good agreement with that captured in video images.

The objective of this paper is to further the fundamental understanding of flycasting mechanics. A mathematical model of fly line will be presented that uses state-of-the-art continuum models from the field of cable dynamics. This continuum model avoids the inevitable modeling assumptions introduced in lumped parameter models and also allows one to directly prescribe important physical properties of the fly line including taper and non-uniform mass. Numerical solutions to this model are discussed and reveal how a loop forms and propagates along the line. As recently noted by Phillips [5], the fly fishing industry may be able to capitalize on such computer simulations of flycasting as a means to understand and improve the casting performance of both fly rods and fly lines.

MODEL AND SIMULATION OF FLY LINE

In this presentation, we will begin by modeling a fly line as a one-dimensional elastic continuum that is able to support tension and bending. In essence, the line is treated as very slender (non-uniform) rod that is allowed to undergo arbitrarily large deformations during casting. An element of this fly line, considered as a free-body, is subject to weight, air drag, and internal tension, shear, and bending moments. The equations of motion of this element will be presented together with constitutive laws for the fly line. The resulting equations of motion constitute a nonlinear initial-boundary-value problem. The boundary conditions are selected to describe the free end of the fly line (vanishing shear and moment) and the attachment to the rod tip (prescribed velocity and vanishing moment). The initial conditions are selected to represent a perfect "back cast" as further described below.

Numerical solutions to the equations of motion are pursued following a three-step strategy similar to that in [6]. The first step is to discretize in time using backward differencing and resulting in a nonlinear boundary-value problem in space. The nonlinear boundary-value problem is then linearized through a first-order Taylor series expansion of the field equations. Finally, this linearized boundary-value problem is transformed into a linear initial-value problem (in space) which is solved exactly. The last two steps are then repeated until a convergence criterion is satisfied. The solution strategy is then advanced to the next time step where the original nonlinear initial-boundary-value problem is updated. Solution convergence is obtained upon refining both spatial and time steps.

RESULTS

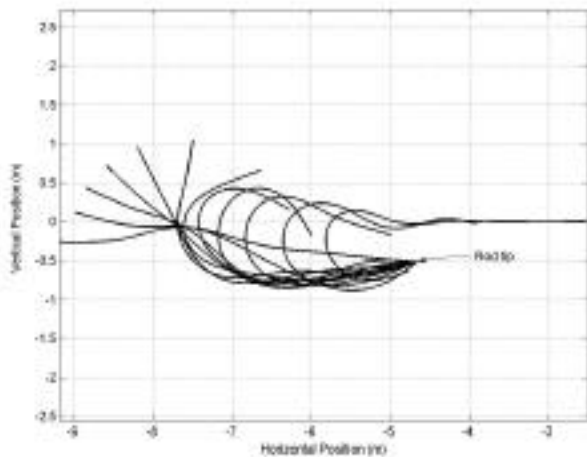


Figure 1. Simulation of a flycast showing the initiation and propagation of a loop to the left.

The model and numerical method described above is used to simulate the dynamics of the fly line during the forward casting phase of a standard overhead cast. The velocity of the rod tip, as represented by boundary conditions, constitutes the input to the cast and this is estimated herein from measurements made from video images [7]. The properties of the line correspond to those of a standard 5-weight, weight-forward, tapered floating line with a casting length of 5 meters. The initial conditions for this simulation (not shown) describe the line ideally laid back horizontally behind the angler and at rest (to the right in Figure 1). These initial conditions describe a perfect back cast. At time $t=0$, the end of the line attached to the rod is given the prescribed motion of the fly rod tip, and in the latter stages of the cast, a loop forms and propagates to the left as depicted in Figure 1 above. Figure 1 illustrates the geometry of the fly line (for 12 selected times) during the latter phase of the forward cast when the rod tip is stationary.

A fundamental understanding of loop formation and propagation can be obtained from the data shown in Figure 2. This figure illustrates the horizontal and vertical velocity components of the end of the line attached to the rod tip as well as the free end. Inspection of this figure reveals that during the first half second of the forward cast, the ends of the fly line have identical velocity components and that the rod tip accelerates the line in the horizontal direction. Thus, during this initial acceleration, the line is nearly straight under appreciable tension

(and behaves essentially as a rigid body.) Shortly after 0.5 seconds, the rod tip decelerates rapidly to a stop at about 0.8 seconds. During this deceleration and beyond, the free end of the fly line has a velocity that is appreciably different from that of the rod tip. This velocity difference is required for the formation of a loop. In fact, the loop propagation speed grows in proportion to the difference in the horizontal velocities at the rod tip and the free end.

Quantitative metrics of casting performance also can be derived from these simulations and used to distinguish competing fly line designs. Proposed casting metrics include loop velocity, loop diameter, loop tension, energy dissipated by air drag, and the like. These metrics will be used in this presentation to further develop our understanding of flycasting mechanics and also to assess the advantages of fly line tapers as primary design variables that affect casting performance.

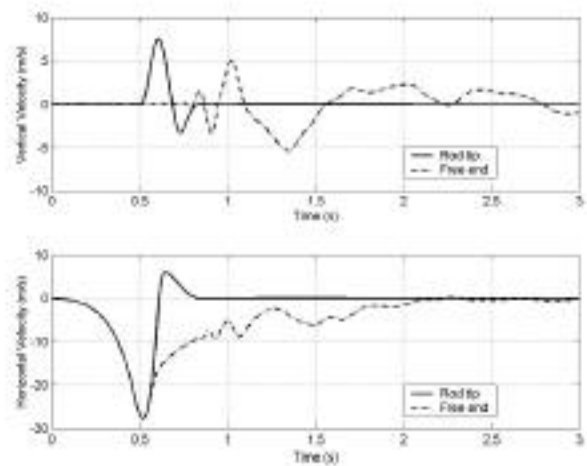


Figure 2. Velocity components of extreme ends of fly line during the forward cast.

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